A New Correlation For Thermal Conductivity of R134a

Su Zhijun

SHANGHAI HITACHI ELECTRICAL APPLIANCES CO., LTD., SHANGHAI,

201206, P.R.C

Sun Zhaopu

SHANGHAI JIAO TONG UNIVERSITY, SHANGHAI, 200030, P.R.C

ABSTRACT

A new multi-constant correlation for thermal conductivity of R134a:

$$I_{j} = \sum_{i=1}^{20} a_{i} b_{ij} \tag{1}$$

is proposed in this paper. This correlation has been tested in subcooled liquid, saturated liquid, superheated vapor and saturated vapor phase. The data used to test the correlation are in the temperature range from 203k to 440k and pressure range form 0.04MPa to 67MPa. The mean deviation between the calculated and experimental value in subcooled liquid phase is 1.405%, in saturated liquid phase is 0.80%, in superheated vapor phase is 2.31%,and in saturated vapor phase is 1.86%. The results show that this correlation has high accuracy and wide application range. It can be used to build the database of thermal conductivity of R134a.

KEY WORD: correlation, method of calculation, R134a, thermal conductivity.

1. INTRODUCTION

Transition properties (such as thermal conductivity, viscosity) are the fundamental data in the design of heat-exchanger and compressor. CFCs are harmful to the ozone, and they be resisted and not allowed to use in the near future. So study on the transition properties of the alternatives of CFCs is very important and necessary. Because the new refrigerants used to replace CFCs aren't investigated thoroughly, the experimental data and the correlations for transition properties aren't plenty. All above may cause

has theoretical and practical significance to development new correlations for transition properties which have high accuracy and wide application range(including wide temperature range and wide pressure range). In this paper, the authors have studied the thermal conductivity of R134a,and proposed a new correlation for the thermal conductivity of R134a that can be used in wide application range.

2. EXPERIMENTAL STUDY ON THERMAL CONDUCTIVITY OF R134a

By now, reports about the studies on thermal conductivity of R134a are listed below:

- 1) In 1991, Tanata^[1] measured the thermal conductivity of R134a in vapor phase,and obtained 33 data. According to the report, the uncertainty of the measurement is 2%,and the purity of the sample is 99.9%.
- 2) Liu Zhigang ^[2]measure the thermal conductivity of R134a at the atmospheric pressure in 1992 ,and obtained 10 data. The claimed uncertainty of the measurement is less than !%. The purity of the sample was not mentioned in his paper.
- 3) Gross ^[3]measured the thermal conductivity of R134a in vapor and liquid phase. Using a concentric cylinder, he obtained 88 data. The investigators points out in the report: The uncertainty of the measurement is 2%, and the purity of the sample is 99.9%.
- 4) Using hot-transient-wire method ,Leaseche^[4] measured the thermal conductivity of R134a in liquid and vapor phase in 1992,and obtained 214 data. According to the report,the uncertainty of the measurement is 3.8%,and the sample contains no more than 85ppm organic impurity and 126ppm water .

- 5) In 1992,Assael^[5] measured the thermal conductivity of R134a in the subcooled liquid phase, and obtained 36 data. According to the reference ,the uncertainty of measurement is 0.5%,and the purity of the sample is 99.9%.
- 6) Yamamoto^[6] measured the thermal conductivity of R134a in superheated vapor phase in 1993. He obtained 51 experimental data. The uncertainty of the measurement is 1%, and the purity of the sample is 99.9%.
- 7) Papadaki^[7] measured the saturated liquid thermal conductivity of R134a in 1993. He obtained 8 experimental dataThe uncertainty of the measurement is 1%,and the purity of the sample is 99.9%.
- 8) Olivera^[8] measured the thermal conductivity of R134a near the saturated liquid line in 1993. He obtained 21 experimental data. The uncertainty of the measurement is 2.7%, and the purity of the sample is 99.9%.
- 9) Liu Mingfu^[9] measured the thermal conductivity of R134a in saturated vapor phase in 1994. He obtained 26 experimental data..The uncertainty of the measurement was not mentioned in the report, and the purity of the sample is 99.95%.
- 10) Tsvetkov^[10] measured the thermal conductivity of R134a in superheated vapor phase in 1995. He obtained 21 experimental data. The uncertainty of the measurement is 3%, and the purity of the sample is 99.83%.

All above are compiled in the table 1.

The authors analyze the data ,and get rid of the data that have obvious error ,and 459 data are obtained.

3. FOUNDATION OF THE CORRELATION FOR THERMAL CONDUCTIVITY OF R134a

Thermal conductivity not only correlates to the temperature ,but also correlates to the pressure or density. After studying ,the authors propose the correlation:

$$\begin{split} & \mathsf{I} = a_1 + a_2 T_r + a_3 T_r \Gamma_r + a_4 \Gamma_r / T_r + a_5 \Gamma_r / T_r^2 + a_6 \Gamma_r / T_r^3 + a_7 \Gamma_r^2 T_r + a_8 \Gamma_r^2 / T_r + a_9 \Gamma_r + a_{10} \Gamma_r^2 / T_r^3 + a_{11} \Gamma_r^3 T_r + a_{12} \Gamma_r^3 / T_r + a_{13} \Gamma_r^3 / T_r^2 + a_{14} \Gamma_r^3 / T_r^3 + a_{15} \Gamma_r^4 / T_r^3 + a_{16} \Gamma_r^4 / T_r^4 \\ & + a_{17} \Gamma_r^5 / T_r + a_{18} \Gamma_r^5 / T_r^2 + a_{19} \Gamma_r^6 / T_r^2 + a_{20} \Gamma_r^6 / T_r^6 \end{split} \tag{1}$$

where a_1, a_2, \dots, a_{20} are the coefficients in the correlation.

$$T_r = T/T_c$$
, $r_r = r/r_c$, $T_c = 374.274 K$, $r_c = 515.25 Kg \cdot m^{-3}$

In order to determine the coefficients in the correlation, the authors change the form of correlation to :

$$I_{j} = \sum_{i=1}^{20} a_{i}b_{ij}$$

where .:

$$b_{1j} = 1, b_{2j} = T_{rj}, b_{3j} = r_{rj}T_{rj}, b_{4j} = r_{rj}/T_{rj}$$

$$b_{5j} = \Gamma_{rj} / T_{rj}^2, b_{6j} = \Gamma_{rj} / T_{rj}^3, b_{7j} = \Gamma_{rj}^2 T_{rj}, b_{8j} = \Gamma_{rj}^2 / T_{rj}$$

$$b_{9j} = \Gamma_{rj}^2 \big/ T_{rj}^2 , b_{10j} = \Gamma_{rj}^2 \big/ T_{rj}^3 , b_{11j} = \Gamma_{rj}^3 T_{rj} , b_{12j} = \Gamma_{rj}^3 \big/ T_{rj} ,$$

$$b_{13j} = \Gamma_{rj}^3 / T_{rj}^2, b_{14j} = \Gamma_{rj}^3 / T_{rj}^3, b_{15j} = \Gamma_{rj}^4 / T_{rj}^3, b_{16j} = \Gamma_{rj}^4 / T_{rj}^4$$

$$b_{17j} = \Gamma_{rj}^5 / T_{ri}$$
, $b_{18j} = \Gamma_{rj}^5 / T_{ri}^2$, $b_{19j} = \Gamma_{rj}^6 / T_{rj}^2$, $b_{20j} = \Gamma_{rj}^6 / T_{rj}^6$

The subscript j is the ordinal number of the experimental data. And N is the total number of the experimental data. Γ_{ij} is the jth calculated thermal conductivity . Γ_{ij} T_{ij} are the reduced density and reduced temperature, respectively. Γ_{ij} is the jth experimental thermal conductivity value.

In order to determine the values of a_1 , a_2 ,....., a_{20} , the authors set up the object function:

$$D = \sum_{j=1}^{n} \left\{ \left| \sum_{bj} - \sum_{i=1}^{20} a_i b_{ij} \right|^2 \right\}$$

According to linear-regression method ,in order to make the value of D the smallest ,the authors get :

$$\frac{\P D}{\P a_1} = \frac{\P D}{\P a_2} = \frac{\P D}{\P a_3} = \frac{\P D}{\P a_{20}} = 0$$

Then the authors get:

$$a_1 \sum_{j=1}^{N} b_{1j}^2 + a_2 \sum_{j=1}^{N} b_{1j} b_{2j} + a_3 \sum_{j=1}^{N} b_{1j} b_{3j} + + a_{20} \sum_{j=1}^{N} b_{1j} b_{20j} = \sum_{j=1}^{N} b_{1j} I_{bj}$$

$$a_1 \sum_{j=1}^{N} b_{2j} b_{1j} + a_2 \sum_{j=1}^{N} b_{2j}^2 + a_3 \sum_{j=1}^{N} b_{2j} b_{3j} + + a_{20} \sum_{j=1}^{N} b_{2j} b_{20j} = \sum_{j=1}^{N} b_{2j} |_{bj}$$

$$a_{1}\sum_{j=1}^{N}b_{20j}b_{1j} + a_{2}\sum_{j=1}^{N}b_{20j}b_{2j} + a_{3}\sum_{j=1}^{N}b_{20j}b_{3j} + +a_{20}\sum_{j=1}^{N}b_{20j}^{2} = \sum_{j=1}^{N}b_{20j}I_{bj}$$

The solutions a_1, a_2, \dots, a_{20} to the equations are the coefficients in correlation (1).

Utilizing the 456 experimental data, the authors use linear-regression method to get the

where the units of the data:

$$T: K.r: kg \cdot m^{-3} : mw \cdot m^{-1} \cdot k^{-1}$$

The experimental data that have been used are in temperature range from 203K to 440k, and in the pressure range from 0.1MPa to 67MPa. The experimental data are in the liquid and vapor phase.

4. COMPARISON AND TEST OF THE CORRELATIONS

The authors compare the calculating accuracy of correlations that have been proposed by the different investigators. The comparison is performed in subcooled liquid phase, saturated liquid phase, saturated vapor phase, superheated vapor phase and all the thermophisical phases. The correlations used are listed as below:

In 1992, Gross^[3] proposed a correlation that is valid in vapor and liquid phase(except the critical range):

$$I(T,r) = a_0 + a_1(T - 273.15) + a_2r + a_3r^2 + a_4r^3 + a_5r^4$$
 (2)

For the saturated vapor thermal conductivity, Gross proposed a correlation as below:

$$I_{SV}(T) = a_1 + a_2(T - 273.15) + a_3(T - 273.15)^2$$
 (3)

For the saturated liquid thermal conductivity, a correlation proposed by Gross is:

$$I_{SL}(T) = a_1 + a_2 T \tag{4}$$

In 1992, Lease che $^{\left[4\right]}$ proposed $\,$ correlations for thermal conductivity of R134a :

For saturated liquid thermal conductivity and superheated vapor thermal conductivity ,the correlation is:

1 (m) . m . m² (e)

but the coefficients are different.

For saturated vapor thermal conductivity the correlation is:

$$I_{SV}(T) = a_1 + a_2 T + a_3 T^2 + a_4 T^3 \qquad (6)$$

For rarefied gas, Krauss^[11] proposed a correlation in 1992:

$$I = a_1 + a_2 T + a_3 T^2 \tag{7}$$

Yamamoto^[6] proposed a correlation for the liquid and vapor thermal conductivity in 1993:

$$I(T,r) = c_1 T + c_2 T^2 + d_0 + d_1 r + d_2 r^2 + d_3 r^3 + d_4 r^4$$
 (8)

He also gave a correlation for the saturated vapor thermal conductivity of R134a in the same reference:

$$I_{SV}(T) = a_1 T + a_2 T^2 + a_3 T / (T_c - T)$$
(9)

Papadaki^[7] proposed a correlation for saturated liquid thermal conductivity of R134a:

$$I_{SL}(T) = 211.07 - 0.4284T \tag{10}$$

Oliveira^[8] Proposed a correlation ,which is valid along the saturated liquid line:

$$I(T) = a_1 + a_2 T \tag{11}$$

 $Tsvetev^{[10]}$ Proposed a correlation for rare gas thermal conductivity of R134a:

$$I = a_1 + a_2 T + a_3 T^2 + a_4 T^3 \tag{12}$$

Asseal^[12] proposed a correlation for the subcooled and saturated liquid thermal conductivity of R134a:

$$log(\lambda^*/R_{\lambda}) = \sum_{i=0}^{4} b_i v_r^{-i}$$
 (13)

where:

$$\lambda^* = 1.936 \times 10^7 \left(M/RT \right)^{0.5} \cdot \lambda v^{2/3} \quad , \qquad v_r = v/v_0 \quad , \qquad R_\lambda = \sum_{j=1}^4 \theta_j T_r^{i-1} \quad , \qquad v_0 = \sum_{j=1}^4 v_j T_r^{j-1} \\ v_j \, , \phi_j \, , b_i \, \text{are constant}, \, T_r = T/T_c$$

It can been seen form above that:

Correlation (1),(2),(4),(5),(8),(10),(11),(13) are valid in the saturated liquid phase , correlation (1),(2),(8),(13) can be used to calculated the subcooled liquid thermal conductivity , correlation (1),(2),(5),(7), (8),(12) are valid in the superheated vapor phase , correlation (1),(2),(3),(6),(8),(9) can be used in the saturated vapor phase, and correlation (1),(2),(8) can be used in all phases.

The results of comparison are listed in table 37.

We can see from table37:

The maximum deviation of correlation(1) in the saturated liquid phase is 2.24%, and the mean deviation is 0.8%. The mean deviation of correlation(1) for the subcooled liquid is 1.405%, for the superheated vapor is 1.86%, and for all the data is 1.93%. The results show that the correlation proposed in this paper has a wide application range and high accuracy.

5. CONCLUSION

A new correlation for the thermal conductivity of R134a is proposed in this paper .It has high accuracy and wide application range .It is valid in all the thermophisical phase ,and has accuracy of 1.93%.

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Table 1.The experimental study on thermal conductivity of R134a

investigator	ref.	year	temp.(K)	pres.(MPa)	uncertainty	method	state	purity	No.
Tanaka	[1]	1991	293.15-313.15	0.1-2.5	2%	cylinder	gas	99.9%	33
Liu Zhigong	[2]	1992	288.36-338.67	0.101325	1%	hot-wire	gas		10
Gross	[3]	1992	253.15-363	0.1-6	2%	cylinder	gas&liq	99.9%	88
Laesecke	[4]	1992	203-393	0.1-67	3.8%	hot-wire	gas&liq		214
Asseal	[5]	1992	253-333	0.64-20	0.5%	hot-wire	liq	99.9%	36
Yamamoto	[6]	1993	273.15-373.15	0.1-3	1%	hot-wire	gas	99.9%	51
Papadaki	[7]	1993	240307	sat	1%	hot-wire	sat.liq	99.9%	9
Oliveira	[8]	1993	227.40-342.97	0.04-2.2	2.7%	hot-wire	liq		7
Liu Mingfu	[9]	1994	233.15-358.15	sat		hot-wire	sat.vap	99.95%	26
Tsvetkov	[10]	1995	235.33-439.51	0.05-0.2	3%	cylinder	gas	99.83%	21

Table 2. The coefficients in the correlation(1)

a_1	-10.653531093600840	a ₁₁	-135.431117092042800
a ₂	30.182606624002720	a ₁₂	1019.311431130637000
a ₃	-37.861646546397760	a ₁₃	-1416.942131226870000
a_4	118.350197301057300	a ₁₄	541.234712556719700
a ₅	-147.83601784513290	a ₁₅	-54.562351101660160
a ₆	60.077330395012570	a ₁₆	-10.667967360955640
a ₇	297.459328281136200	a ₁₇	-26.846611391950350
a_8	-1814.3740807713720	a ₁₈	63.932260016614430
a ₉	2303.68875883621500	a ₁₉	-6.072423402696970
a ₁₀	-727.95026167951630	a ₂₀	2.811526174478536E-002

Table 3. Comparison in saturated liquid phase(data from ref.[7,8])

correlation (2)		correlation (4)		correlation (5)		correlation (8)	
maximum	mean deviation						
deviation		deviation		deviation		deviation	
5.63%	1.73%	1.45%	0.81%	8.43%	2.03%	14.1%	3.97%
correlation	(10)	correlation	(11)	correlation	(13)	correlation	(1)
maximum	mean	maximum	mean	maximum	mean	maximum	mean
deviation	deviation	deviation	deviation	deviation	deviation	deviation	deviation
2.88%	0.92%	1.79%	0.55%	10.7%	3.75%	2.24%	0.80%

Table 4. Comparison in subcooled liquid phase (data from ref.[3,4,5])

correlation	correlation	correlation	correlation
(2)	(8)	(13)	(1)
mean	mean	mean	mean
deviation	deviation	deviation	deviation
5.94%	4.278%	4.531%	1.405%

Table 5. Comparison in superheated vapor phase (data from ref.[1,2,3,4,6,10])

correlation	correlation	correlation	correlation	correlation	correlation
(2)	(5)	(7)	(8)	(12)	(1)
mean	mean	mean	mean	mean	mean
deviation	deviation	deviation	deviation	deviation	deviation
5.19%	6.94%	6.33%	3.277%	2.82%	2.31%

Table 6. Comparison in saturated vapor phase (data from ref.[10])

correlation	correlation	correlation	correlation	correlation	correlation
(2)	(3)	(6)	(8)	(9)	(1)
mean	mean	mean	mean	mean	mean
deviation	deviation	deviation	deviation	deviation	deviation
4.4%	1.324%	11.6%	3.8%	5.8%	1.86%

Table 7. Comparison in all phases (data from ref.[1,2,3,4,5,6,7,8,9,10])

correlation(2)	correlation(8)	correlation(1)
mean deviation	mean deviation	mean deviation
4.54%	3.86%	1.93%